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Original Article

TRANSFER TIME REDUCTION IN LTE NETWORK FOR IMPROVED PERFORMANCE USING MIXED SENSITIVITY TECHNIQUE

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ABSTRACT: In LTE networks, Transmission Control Protocol (TCP) performance degrades when number of connections increases. To ameliorate this situation, there is need to improve on the performance criteria: specifically, the settling time (transfer time). This work proposes reduction in the settling time of the system network by applying a mixed sensitivity technique. Mixed Sensitivity Optimization Synthesis (Mixsyn) technique is a robust approach that involves the development of a robust compensator and the application of weighting functions to boost the performance of LTE wireless broadband. The enhanced TCP performance of the system was achieved by reducing the settling time (transfer time) to 0.00043seconds and 0.000425 seconds, which is 99.57% and 99.575% of the time base value of 0.1 seconds of the system. With this result, the Mixsyn technique was used to improve the TCP based LTE network. The results show an improved implementation and steadiness of the system. In conclusion, the Mixsyn technique achieved an improved performance and steadiness of the system even in times of skepticism.

KEYWORDS: TCP, LTE, Mixsyn, Settling Time, Sensitivity to disturbance.

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1.0 INTRODUCTION

Growth in information communication technology especially in telecommunication industries is inevitable. This growth has led to the demand for higher speed data transfer for different personal and business transactions and has equally brought about tremendous growth of data usage in business, individual and government transactions on the mobile networks. With these, there are data congestion and interference leading to degradation of network performance. There have been various research works to proffer solutions. LTE brought about high speed data transfer, but equally suffers various forms of disturbances due to its interaction with the TCP. The 4G network concentrated on information services which supports virtual circuit switching; virtual circuit switched networks manages transient traffic bursts with the aid of a buffering circuit [1].

To address the problem of congestion in TCP, the Proportional Integral Derivative (PID) in [2] is used but the high overshoot in the results did not ensure the desired enhancement of the performance of the system. This problem of PID results from the limitation in its turning technique and selection of the controller gains. The problem of limitation in its tuning capability is achieved using mixed sensitivity synthesis (mixsyn) in this work. This method applies weighting functions without limitations on TCP queues to enhance efficiency of the performance characteristics of the transmission control protocol cue over LTE pack through loop shaping. Hence this mixed sensitivity synthesis finds a controller that can improve the system and satisfy the desired system characteristics. LTE network requires a reliable data transfer protocol such as TCP. Since the TCP is a reliable data

transfer protocol with speed as a major drawback factor, this work focuses on improving the TCP based LTE network speed.

2.0 LTE WIRELESS MOBILE NETWORK

LTE is a 3GPP with an all-IP wireless protocol that evolved from GSM [3]. LTE increases the capacity, coverage, speed and provision of significant increase in spectrum efficiency [1]. Secondly, The System Architecture Evolution (SAE) structure facilitates the pith network efficacy while guaranteeing interactive features with existing packs such as HSPA [4]. LTE is assurable for users of HSPA networks [5]. Far back to 2009, LTE has been instated as a usu expansion of GSM along side UMTS. LTE adopts access strategies such as that of Frequency Division Duplexing (FDD) and also Time Division Duplexing (TDD) [6]. LTE provides increased spectral effectiveness, reduced latency and increased apex rate of data. The Long term evolution technology has been known with the notion that it enhances the effectiveness of data rate, throughput, low latency, and cost in a system. LTE makes available pure packets assigned structure, with workability in mobility intendance [4].

2.1 Active Queue Management (AQM)

The AQM which is also referred to as the buffer bloat helps to solve the problem of congestion during communication between two devices. AQM has made available some congestion control methods [7]. Nevertheless, as a result of the nonlinear structure of the dynamic model, the performance does not adequately enhance the system using AQM. Because of the nonlinear nature of the dynamic mods, the models are now linearized with the aid of Proportional Integral (PI) congestion controllers at an equilibrium point. Though, this linearized models are dependent on time delay. It is convincing to obtain better constancy and performance for models which possess time delay.

2.2 Transport Control Protocol (TCP)

Transmission Control Protocol (TCP) manages the process of data flow to prevent the loss of data due to congestion. The technique used to improve the effectiveness of TCP is to revamp the TCP because TCP exhibits one basic reason for petty and bad performance in wireless contexture. The dominant window size strategy often possesses much data in flight. Data in Flight refers to the quantity of data transmitted but yet to be acknowledged or confirmed to be received. Thou, the sender has no means to quantify the link magnitude other than filling the network yet causing packet loss. The performance and effectiveness of TCP in mobile networks in [9] demonstrates that load increase in cell causes reduction of bandwidths on UEs and absolute degradation in the performance of the TCP. Non Ideal handover necessitates TCP loss while ideal handover necessitates the increase in segments' delay of the TCP [8]. TCP protocol is mostly used in wireless systems and wireline systems. However, they are not primarily designed for wireless networks and real time applications. [3].

TCP ascertains congestion by viewing time-out processing and then adjusting TCP window sizes of sending devices [9]. However, this control method has low efficiencies during communication because it avoids congestion after congestion appeared once in networks [10]. To achieve good performance efficiency and reliability in the network, several research in congestion control has been done using system theory as well as control theory. The design of controllers using control theory has been proposed and applied in many research but in most cases, they achieved improved performance. TCP is a protocol that offers relevant features in process flow control, system reliability, and congestion management as well as connection intendance. However, it under- performs in high data traffic networks. Hence, in order to enhance the performance of TCP in a wireless system, it is ideal to cut down congestion window size but it further results in

performance degradation [11]. The problem becomes more serious in increasingly busy or nearly congested networks with fast changes in it's topology [12]. TCP protocol offers an end-to-end connection and flow rate management with a two directional link and reliability of the data [13].

3.0 CONGESTION CONTROL

The Bottleneck Bandwidth and Round-trip propagation time algorithm (BBR) is a new technique for congestion management. [14] This congestion management technique makes use of a round trip time and bottleneck bandwidth probing cycle to keep bottleneck queue load on a low level along with queuing delays and tries to reach effective bottleneck capacity utilization. Such a technique under some conditions leads to a higher performance in comparison to loss-based or "delay-loss-based" algorithms [15]. However, the probing cycle leads to data rate decrease and in some cases to unfair resource sharing [16].

There are several techniques such as the RED and its alternates such as the Adaptive RED (ARED) [17]. CARED[18], Nonlinear RED (NL-RED) [19], The Refined Adaptive RED (Re-ARED) [20], Stabilized RED (SRED) in [21]. Cautious Loss ratio based RED (LRED) in [22] Exponential RED [23], Dynamic RED (DRED) [24], FIF-RED [25] and FEEDBACKS PD-RED [26]. These REDs are designed to control TCP queue. However, REDs require appropriate parameter tuning to get better performance though practically difficult to achieve. In recent times, much research attention is given to the steadiness and toughness of the AQM [27]. In the bid to ensure the queue length remains stable, new AQM in routers uses management theory to conquer the multiple delays problem [28]. A mathematical model developed in [29] analyzes the AIMD/RED steadiness of the system.

3.1 TCP Dynamic Model

This section discusses the fluid flow idea and it depicts an ideal system. It provides system parameters that explain its behavior. A mathematical analysis for the behavior of the TCP proposed in [30]. It addresses two workable retransmission causes: the triple duplicate ACKs and time out.:

$$\dot{W}(t) \approx \frac{1}{R(t)} + \left(1 - Q(W)\right)\left(-\frac{W(t)W\left(t - R(t)\right)}{2R\left(t - R(t)\right)}\right) \ldots.$$

$$\ldots \ldots p\left(t - R(t)\right) + \left(1 - W(t)\right)Q(W)\frac{W\left(t - R(t)\right)}{R\left(t - R(t)\right)}p\left(t - R(t)\right)$$

$$\dot{q}(t) = \sum_{t=1}^{N} \frac{W(t)}{R(t)} - C \tag{1}$$

Where

- *W = window size of TCP*
- *q = length of the queue*
- *R = RTT*
- *C = capacity of the link*
- *N = number of TCP sessions*

- *p = probability of each packet dropped*
- *t = time (s)*

The relation $Q(W)$ detects the chances of one loss resulting from the timeout (instead of a triple duplicate ACK been its cause.), size of the window is *W as at when the loss occurs*. A simplified expression is $Q(W) = \min(1, 3/W)$. The simplified model presented in [16] ignores the timeout mechanism but is well suited for performing a small-signal linearization. The resulting model becomes;

$$\dot{W}(t) = \frac{1}{R(t)} - \frac{W(t)W\big(t - R(t)\big)}{2R\big(t - R(t)\big)} p\big(t - R(t)\big)$$

$$\dot{q}(t) = \frac{W(t)}{R(t)} N(t) - C \tag{2}$$

Considering;

(W, q) = state of the system.

p = input of the system, the operating point (W_0, q_0, p_0) is then denoted by $\dot{W} = 0$ and $\dot{q} = 0$hence the following factors are detailed as:

$$W_0^2 p_0 = 2 \tag{3}$$

$$W_0 = \frac{R_0 C}{N} \tag{4}$$

$$R_0 = \frac{q_0}{C} + T_p \tag{5}$$

Linearizing Equation 1 yields:

$$\begin{cases} \delta\dot{W}(t) = -\frac{N}{R_0^2 C}\big(\delta W(t) + \delta W(t - R_0)\big) - \frac{R_0 C^2}{2N^2}\delta p(t - R_0) \\ \qquad \delta\dot{q}(t) = \frac{N}{R_0}\delta W(t) - \frac{1}{R_0}\delta q(t) \end{cases} \tag{6}$$

Where, $\delta W = \dot{W} - W_0$, $\delta\dot{q} = q - q_0$, $\delta\dot{p} = p - p_0$denotes the disturbed variables around the point of operation.

Considering distinct network conditions produces]:

$$\frac{N}{R_0^2} = \frac{1}{W_0 R_0} \ll \frac{1}{R_0}$$

$$\begin{cases} \delta\dot{W}(t) = -\frac{2N}{R_0^2 C}\delta W(t) - \frac{R_0 C^2}{2N^2}\delta P(t - R_0), \\ \qquad \delta\dot{q}(t) = \frac{N}{R_0}\delta W(t) - \frac{1}{R_0}\delta q(t) \end{cases} \tag{7}$$

Performing Laplace transform gives:

$$\begin{cases} G_W(s) = \dfrac{\frac{R_0 C^2}{2N}}{\left(s + \frac{2N}{R_0^2 C}\right)} \\ \\ G_q(s) = \dfrac{\frac{N}{R_0}}{\left(s + \frac{1}{R_0}\right)} \end{cases} \tag{8}$$

Where$G_W(s)$represents the TCP dynamic model without time delay and $G_q(s)$represents the queue dynamic model.

3.2 Problem Set Up.

Mix-Synthesis also known as mixsyn takes care of the plant *G by designing a controller k for it.*, assuming the following diagram's standard control configuration. Figure 3 explains the controlled system using the controller K.To arrive at the K, the function a attaches the weighting functions provided, $W_1(s)$, $W_2(s)$, and $W_3(s)$, to the control system, as displayed in Figure 1.

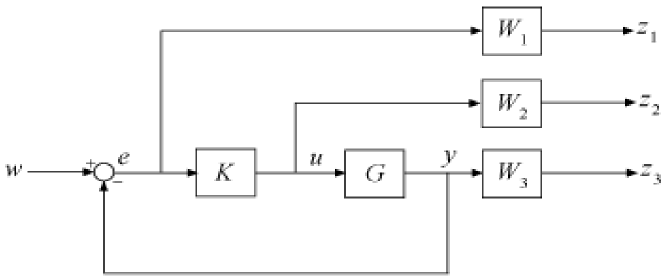

Figure 1: Controlled System with Weights [21].

Mixsyn attends to the challenges as an H_∞ synthesis problem. It simplifies the weighted control system as thou a Linear Fractional Transformation *LFT* (*P*,*K*), such that P is an augmented plant *P* such that {*z*;*e*} = *P*{*w*;*u*}, as shown below in Figure 2.

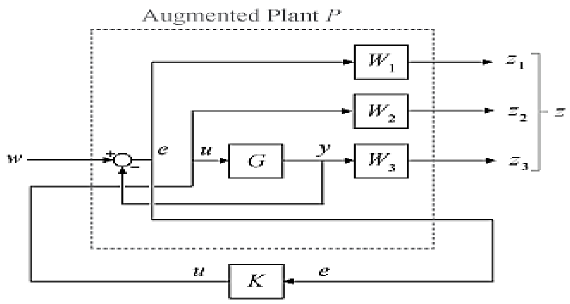

Figure 2: Controlled System with Augmented Plant P.

The transfer function from *w* to *z*is stated as:

$$M(s) = \begin{bmatrix} W_1 S \\ W_2 KS \\ W_3 T \end{bmatrix} \tag{9}$$

Where

- $S = (I + GK)^{-1}$ functions sensitivity.
- KS is the transfer function from *w* to *u* (the control effort).
- $T = (I - S) = GK(I + GK)^{-1}$ is the complementary sensitivity function.

mixsyn desires a controller *K* that minimizes $\|M(s)\|_\infty$, the H_∞ norm (peak gain) of *M*. To realize this, it brings in

mixsyn on the augmented plant:

P = augw(G,W1,W2,W3) (10)

3.3 Weighting Functions

To choose or select the weighting functions the following points are followed: Firstly, for loop gain $L = GK$, to realize desirable reference tracking and disturbance rejection, increasing loop gain at a minimal frequency is required. Secondly, to realise turdiness and attenuation of noise been measures, L is required to roll off at high frequency. The shape of this loop is the same to small S at low frequency and small T at high frequency. For mixed-sensitivity loop shaping, weighting functions are chosen to specify those target shapes for S and T as well as the control effort KS. The H_∞ design constraint,

$$\|M(s)\|_\infty = \left\| \begin{matrix} W_1 S \\ W_2 KS \\ W_3 T \end{matrix} \right\|_\infty \leq 1 \tag{11}$$

This implies that

$$\|S\|_\infty \leq |W_1^{-1}| \tag{12}$$

$$\|KS\|_\infty \leq |W_2^{-1}| \tag{13}$$

$$\|T\|_\infty \leq |W_3^{-1}| \tag{14}$$

Hence, the weights are adjusted to be equivalent to the reciprocals of the shapes desired forKS, T and S. Specifically:

- For to realize desirable reference-tracking and disturbance-rejection performance, useW_1 large inside the control bandwidth to arrive at small S.
- For sturdiness and noise attenuation, selectW_3 large outside the control bandwidth to arrive at small T.
- To limit the control effort in a specific frequency band, increase the magnitude of W_2in this frequency band so small *KS can be gotten*.

mixsyn returns the minimum $\|M(s)\|_\infty$ in the output argument gamma. For the returned controller K, then:

$$\|S\|_\infty \leq \gamma|W_1^{-1}| \tag{15}$$

$$\|KS\|_\infty \leq \gamma|W_2^{-1}| \tag{16}$$

$$\|T\|_\infty \leq \gamma|W_3^{-1}| \tag{17}$$

Therefore if there is no restriction on control effort, W_2 can be omitted. In such instance, the mixsyn reduces theH_∞ is res norm of:

$$M(s) = \begin{bmatrix} W_1 S \\ W_3 T \end{bmatrix} \tag{18}$$

4.0 METHODOLOGY

If the TCP measured time is high, which means that the speed of the TCP over LTE network is low, then the spectrum utilization will be low and such will cause poor performance of the network. It will also increase the error rate, which affects the accuracy and reliability of the network. Thus the lower the time of packet delivery, the better the network speed.

4.1 TCP Performance Improvement Using Mixed Sensitivity Synthesis

The mixed-synthesis involves the use of weighting factors W1 and W2 on the TCP queue plant to achieve the desired system performance. It forms the augmented function using the weighting functions and the TCP queue plant. The methods find the value of the controller C_k that can improve the performance of the system through loop shaping which involves the tuning of the weighting functions.

The mixed synthesis controller design method uses the MATLAB syntax “aug” to connect the weighting functions with the TCP queue transfer function to form the augmented function. It uses the MATLAB syntax “mixsyn” or “hinfsyn” to find the controller C_k which satisfies the desired performance through loop shaping. The TCP performance improvement involves the reduction of the settling time and the tracking error. These characteristics determine how fast and accurate the TCP queue over LTE network performs. Figure 3 shows the controlled system with weighting functions W1 and W2. Figure 4, shows the controlled system with the augmented function.

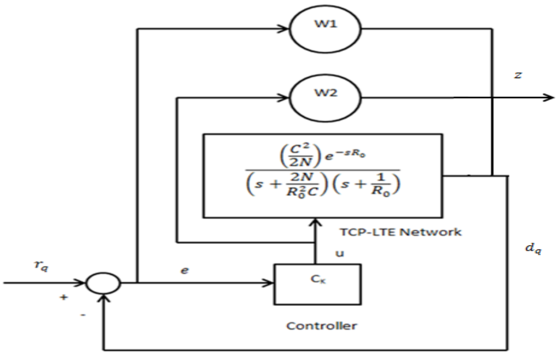

Figure 3: Controlled System with Weighting Functions W1 And W2.

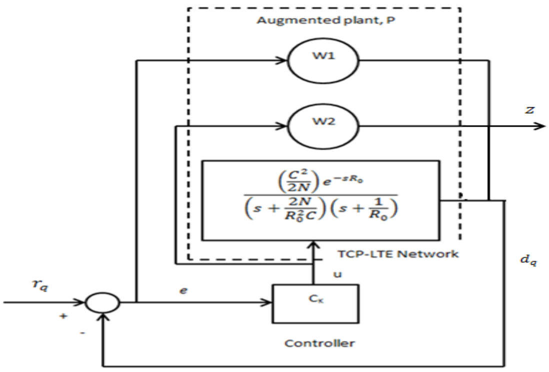

Figure 4: Controlled System with the Augmented Factor

The augmented factor is made up of the weighting factors and the TCP queue plant. This is formed using the MATLAB syntax:

```
>>aug(G, W1, W2)
```

The mix-synthesis algorithm is presented as follows:

- Apply TCP queue transfer function,

$$G_p(s) = \frac{\left(\frac{C^2}{2N}\right)e^{-sR_0}}{\left(s+\frac{2N}{R_0^2C}\right)\left(s+\frac{1}{R_0}\right)} \tag{19}$$

- Formulate the improved system function

$$\partial(s) = \frac{\frac{C^2C_ke^{-sR_0}}{2N}}{\left(s+\frac{2N}{R_0^2C}\right)\left(s+\frac{1}{R_0}\right)+\frac{C^2C_ke^{-sR_0}}{2N}} \tag{20}$$

- Find the controller C_k using mixed-synthesis design method through MATLAB simulation that can enhance the system's output and satisfy the desired characteristics.
- Apply the weighting functions W1(s) and W2(s) on the TCP queue transfer function $G_p(s)$
- Form the augmented function P(s) with Gp(s), W1(s) and W2(s) using MATLAB operator, aug:

$$P(s) = aug(Gp, W1, W2)$$

- Generate the controller C_k in state space using the mixsyn syntax in MATLAB:

$$[C_k] = mixsyn(P)$$

- Compute the open loop gain function:

$$L = C_k \times P$$

- Compute the sensitivity function:

$$S = (1 + L)^{-1}$$

- Plot a time graph for the improved system function $\partial(s)$ to determine the settling time, overshoot and steady state error.
- Plot a frequency graph for the improved system function $\partial(s)$ to determine the tracking error.

The algorithm for the controller design using mixed-synthesis technique is implemented in MATLAB m-file for the TCP queue performance improvement and analysis.

Table 1: Simulation Parameters for the LTE Network [31] [32].

Parameter	Value
Capacity of the link, C	3750 or 4200 packets/s
Round Trip Time, R	0.25s
Bandwidth of Server link	100Mbps
Load Factor, N	60
Packet Size	1500 Bytes
Window Size	48 Kbytes
Simulation Time	30 sec

Substituting the parameters of the TCP based LTE network in table into the system transfer function G:

For link capacity C=3750 packet/seconds

$$G = \frac{25310000000}{s^2+4.002s+0.008} \tag{21}$$

For link capacity C=4200 packet/seconds

$$G = \frac{31750000000}{s^2 + 4.002s + 0.007143} \quad (22)$$

5.0 RESULTS AND ANALYSIS

The modified LTE network using mixed sensitivity synthesis shows the improved TCP based LTE network performance based on the damping time of the modified LTE system output response. The compensator that can help to improve the LTE network was developed in experiments by modifying the weighting functions.

Experiment I

This was carried out in three scenarios: when the link capacity is 3750, 4200 and 4500 using the weighting functions as expressed as follows:

$$W1 = \frac{1000(0.001s + 10)}{s + 10} \quad (23)$$

$$W2 = tf\left(\frac{1}{0.1}\right) \quad (24)$$

First Scenario of First Experiment I - When C=3750 Packet/Seconds:

The first scenario of experiment I was carried out using TCP based LTE network link capacity =3750 packet/seconds:

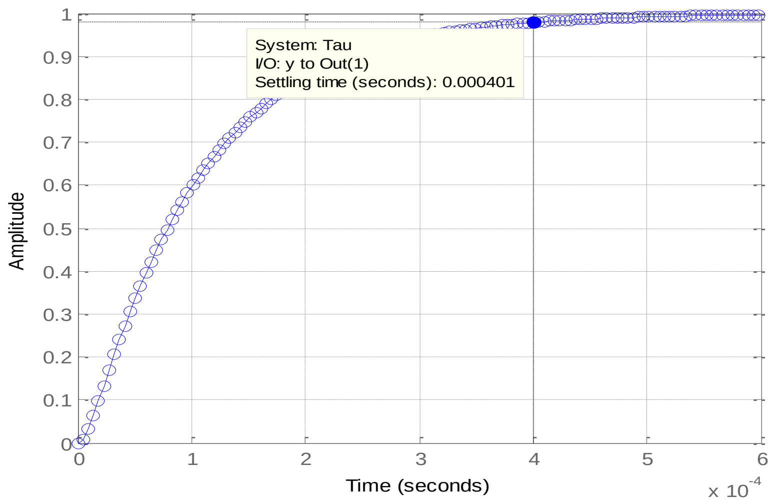

Figure 5: The Time Response of LTE Network When C=3750 Packets/Seconds.

The results in Figure 5 shows that: The modified LTE network achieved damping time of 0.000401 seconds. This means that the modified LTE network using mixed sensitivity synthesis achieved a faster system. This indicates that the modified LTE network will cancel the traffic congestion within 0.000401 seconds.

Second Scenario of First Experiment-When Link Capacity is 4200 Packet/Seconds:

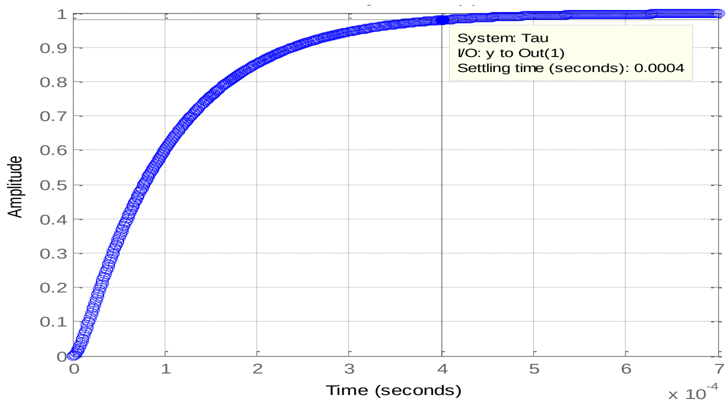

Figure 6: The Time Response of LTE Network When C=4200 Packet/Seconds.

The results in Figure 6 shows that: the modified LTE network achieved damping time of 0.0004 seconds. This means that the modified LTE network using mixed sensitivity synthesis achieved a faster system. This indicates that the modified LTE network will take 0.0004 seconds to cancel the traffic congestion.

The developed compensator Ck using mixed sensitivity synthesis for the second experiment with link capacity of 4200 and weighting functions in equations 23 and 24 is expressed in state space:

Experiment II

This was carried out in two scenarios: when the link capacity is 3750 packet/seconds and 4200 packets/seconds using the weighting functions as expressed as follows:

$$W1 = \frac{1000(0.001s+10)}{s+10} \tag{25}$$

$$W2 = tf\left(\frac{1}{0.01}\right) \tag{26}$$

The first scenario of experiment I was carried out using TCP based LTE network link capacity =3750 packets/seconds:

First Scenario of Experiment II - When C=3750 Packet/Seconds:

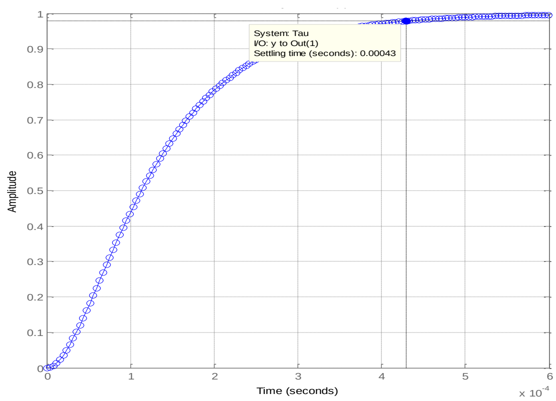

Figure 7: The Time Response of LTE Network When C=3750 Packets/Seconds

The results in Figure 7 shows that: the modified LTE network achieved damping time of 0.00043 seconds. This means that the modified LTE network using mixed sensitivity synthesis will achieve a fast packet transfer. This indicates that the modified LTE network will take 0.00043 seconds to cancel the traffic congestion.

Second Scenario of Experiment II - When C=4200 Packet/Seconds

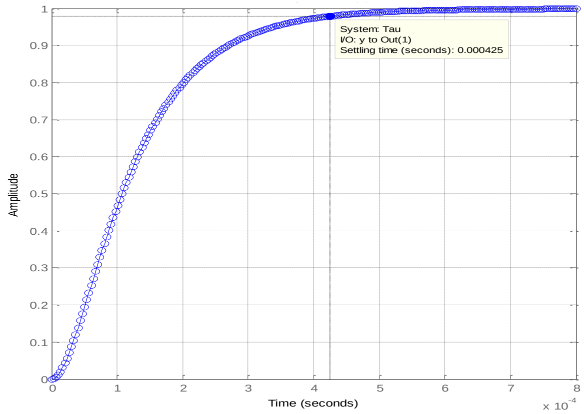

Figure 8: The Time Response of LTE Network When C=4200 Packet/Seconds

The results in Figure 8 shows that: the modified LTE network achieved damping time of 0.000425 seconds. This means that the modified LTE network using mixed sensitivity synthesis will achieve a fast packet transfer. This indicates that the modified LTE network will take 0.000425 seconds to cancel the traffic congestion.

The developed compensator Ck using mixed sensitivity synthesis for the second experiment with link capacity of 4200 packets/seconds and weighting functions in equations 25 and 26 is expressed in state space:

Table 2: Summary Of Improved LTE Network Performance Using Mixsyn

Parameter	Expt. I First Scenario	Expt. I Second Scenario	Expt. II First Scenario	Expt. II Second Scenario
Damping Time (sec)	0.000407	0.0004	0.00043	0.000425
Error (dB)	3.07	0.427	1.14	1.07
Sensitivity to Disturbance (dB)	0.00948	0.00587	0.0059	0.0116

The results in table 2 show that

CONCLUSIONS

The system transfer-time reduction was achieved using the mixed sensitivity synthesis method. LTE network has been known for high speed data transfer but the TCP based LTE network performance becomes easily affected when data packet transfer is not successful as a result of traffic congestion.

This work recommends that: TCP based LTE network performance improvement using mixed sensitivity synthesis should be applied in the current LTE networks in order to help enhance the data packet transfer.

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